KEITHLEY

Instruction Manual

Model 414S
Linear Picoammeter

Keithley Instruments, Inc.
28775 Aurora Road/Cleveland, Ohio 44139/(216) 248-0400

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof which, within a year after shipment, proves defective upon examination. We will pay local domestic surface freight costs.

To exercise this warranty, write or call your local Keithley representative, or contact Keithley headquarters in Cleveland, Ohio. You will be given prompt assistance and shipping instructions.

REPAIRS AND CALIBRATION

Keithley Instruments maintains a complete repair and calibration service as well as a standards laboratory in Cleveland, Ohio.

A Keithley service facility at our Munich, Germany office is available for our customers throughout Europe. Service in the United Kingdom can be handled at our office in Reading. Additionally, Keithley representatives in most countries maintain service and calibration facilities.

To insure prompt repair or recalibration service, please contact your local field representative or Keithley headquarters directly before returning the instrument. Estimates for repairs, normal recalibrations and calibrations traceable to the National Bureau of Standards are available upon request.

KEITHLEY

Keithley Instruments, Inc./28775 Aurora Road/Cleveland, Ohio 44139/U.S.A./(216) 248-0400/Telex: 98-5469
Keithley Instruments GmbH/Heiglhofstrasse 5/D-8000 München 70/WEST GERMANY/(089) 714-40-65/Telex: 521 21 60
Keithley Instruments, Ltd./1, Boulton Road/GB-Reading, Berkshire RG2 ONL/GREAT BRITAIN/(0734) 86 12 87/Telex: 847047
Keithley Instruments SARL/2 Bis, Rue Léon Blum/B.P. 60/91121 Palaiseau Cedex/FRANCE/(6) 011.51.55/Telex: 600933F
Keithley Instruments B.V./Leidsestraatweg 149/Postbus 1190 /NL-Woerden/NETHERLANDS/(03480) 13 643/Telex: 40 311
Keithley Instruments SA/Filiale Dübendorf/Kriesbachstr. 4/CH-8600 Dübendorf/SWITZERLAND/01 821 94 44/Telex: 57 536
Keithley Instruments Handels-Gesellschaft m.b.H./Döblinger Hauptstr. 32/A-1190 Wien /AUSTRIA/0222 314 289/Telex: 13 45 00

INSTRUCTION MANUAL

MODEL 414S

PICOAMMETER

COPYRIGHT 1977, KEITHLEY INSTRUMENTS, INC.
PRINTED, FEBRUARY, 1981, CLEVELAND, OHIO, U.S.A.
DOCUMENT NO. 29101, REV. B

CONTENTS

SECTION	PAGE
ILLUSTRATIONS	iii
SPECIFICATIONS	iv
1. GENERAL DESCRIPTION	1
2. OPERATION	4
3. CIRCUIT DESCRIPTION	6
4. SERVICING	8
5. CALIBRATION	10
6. ACCESSORIES	16
7. REPLACEABLE PARTS	19
SCHEMATICS	27

ILLUSTRATIONS

Fig. No.	Title	Page
1	Front Panel Controls	3
2	Rear Panel Controls	3
3	Divider Circuits Across Picoammeter Output	5
4	Simplified Diagram for Ammeter Circuit	6
5	Test Set-up for Rise Time Check	11
6	Chassis, Top View	14
7	Component Layout, PC180	15
8	Top Cover Assembly	25
9	Bottom Cover Assembly	25

SPECIFICATIONS

RANGE: 10^{-10} ampere full scale to 10^{-2} ampere in seventeen 1x and 3x ranges, positive or negative currents.

ACCURACY: ±2% of full scale on 10^{-2} to 10^{-8} ampere ranges; ±4% of full scale on 3 x 10^{-9} to 10^{-10} ampere ranges.

ZERO DRIFT: Less than 0.5% of full scale per week plus 0.05% per °C on any range after a 10-minute warm-up and with source voltages greater than 1 volt.

INPUT VOLTAGE DROP: Less than 1 millivolt for full-scale meter deflection on any range when properly zeroed.

EFFECTIVE INPUT RESISTANCE: Less than 0.1 ohm on 10^{-2} ampere range, increasing to less than 10^{7} ohms on 10^{-10} ampere range.

RISE TIME, MAXIMUM: Seconds, from 10% to 90%.

Range, ampere	With up to 500 pF Across Input
10^{-10}	0.75
10^{-9}	0.15
10^{-8}	0.13
10^{-7}	0.09
10^{-6}	0.05
10^{-5} and above	less than 0.001

MAXIMUM INPUT OVERLOAD:

Transient: 1000 volts for up to 3 seconds using a Keithley (or other 10 mA limited) High Voltage Supply.

Continuous: 600 volts on 10^{-10} to 10^{-6} ampere ranges, decreasing to 12 volts on the 10^{-2} ampere range.

CURRENT SUPPRESSION: (Model 414S only): Up to 100 times full scale.

Suppression Range: 10^{-9} ampere to 10^{-3} ampere in 7 decade steps, precision 10-turn potentiometer for interpolation between steps. Selectable polarity.

CONNECTORS: Input: Teflon-insulated UHF type. Output: Amphenol 80PC2F.

RECORDER OUTPUT:

Output: ±1 volt or 1 milliampere for full-scale meter deflection. Output polarity is opposite input polarity.

Noise: 414S: Less than 0.3% of full scale peak-to-peak. 414A: Less than 1% of full scale peak-to-peak.

POWER: 105-125 or 210-250 volts (switch selected), 50-60 Hz, 5 watts.

DIMENSIONS, WEIGHT: 5½" high x 8½" wide x 10" deep; net weight, 8 pounds.

ACCESSORIES SUPPLIED: Mating input and output connectors.

SECTION 1. GENERAL DESCRIPTION

1-1. GENERAL.

a. The Keithley Model 414S is a completely solid-state pcioammeter which measures currents over 17 ranges from 10^{-2} to 10^{-10} ampere full scale. Accuracy is ±2% of full scale on the 10^{-2} to 10^{-8} ampere ranges and ±4% of full scale on the 3 x 10^{-9} to 10^{-10} ampere ranges.

b. The Picoammeter employs matched MOS FET transistors in the input followed by a differential amplifier stage, a transistor driver and a transistor output stage. Negative feedback is used for stability and accuracy.

1-2. FEATURES.

a. The time and temperature stability of the 414S Picoammeter is unmatched by any other inexpensive picoammeter. The Model 414S will operate for days without requiring rezeroing. Zero drift with time is less than 0.5% of full scale per week. Temperature drift is equally small - a change of 10°C affects the reading less than 0.5% of full scale on the most sensitive range.

b. A unique circuit provides complete overload protection for Model 414S without compromising the outstanding features of the MOS FET input. The Picoammeter will withstand transient overloads up to 1000 volts without damage, and overload recovery is almost instantaneous.

c. Fast warm-up is an inherent characteristic of the Picoammeter. It can be used almost immediately on its most sensitive range. For maximum stability, however, about 10 minutes warm-up time should be allowed.

d. One volt or 1 milliampere at full-scale deflection on all ranges is provided to drive chart recorders. The 1 milliampere recorder output will drive the Keithley 370 Recorder directly. When potentiometric recorders are used, the output voltage can be conveniently divided by a shunt resistor and adjusted for full scale with the rear panel Calibration potentiometer.

TABLE 2.
Front Panel Controls

Control	Functional Description	Par.
RANGE Switch	Selects full-scale current range instrument is to measure.	2-2
METER Switch	Turns instrument on; selects meter polarity; checks instrument zero.	2-2
ZERO ADJ. Control	Zeroes meter on any range.	2-2
Pilot Light	Glows to indicate instrument is on.	---
SUPPRESSION, MAX AMPERES Switch	Selects suppression current magnitude and turns suppression current off.	2-2
SUPPRESSION, FINE and Polarity Switch	Concentric switches: one determines polarity of suppression current, the other (FINE) varies the suppression from zero to maximum set by the MAX AMPERES Switch.	2-4

TABLE 3.
Rear Panel Controls

Control	Functional Description	Par.
INPUT Receptacle	Connects input to source. Receptacle is a Teflon insulated UHF Connector.	2-1
OUTPUT Receptacle	Connects output to monitoring device.	2-5
1 MA — 1 V Switch	Selects output of instrument: 1 milliampere or 1 volt.	2-5
1 MA CAL Control	Adjusts output from 0.95 to 1.05 mA.	2-5
117-234 V Switch	Sets instrument for 117 or 234 volt ac power line.	2-2
Fuse	3AG Slow-Blow. 117 volt - .125 A; 234 volt - .062 A.	2-6

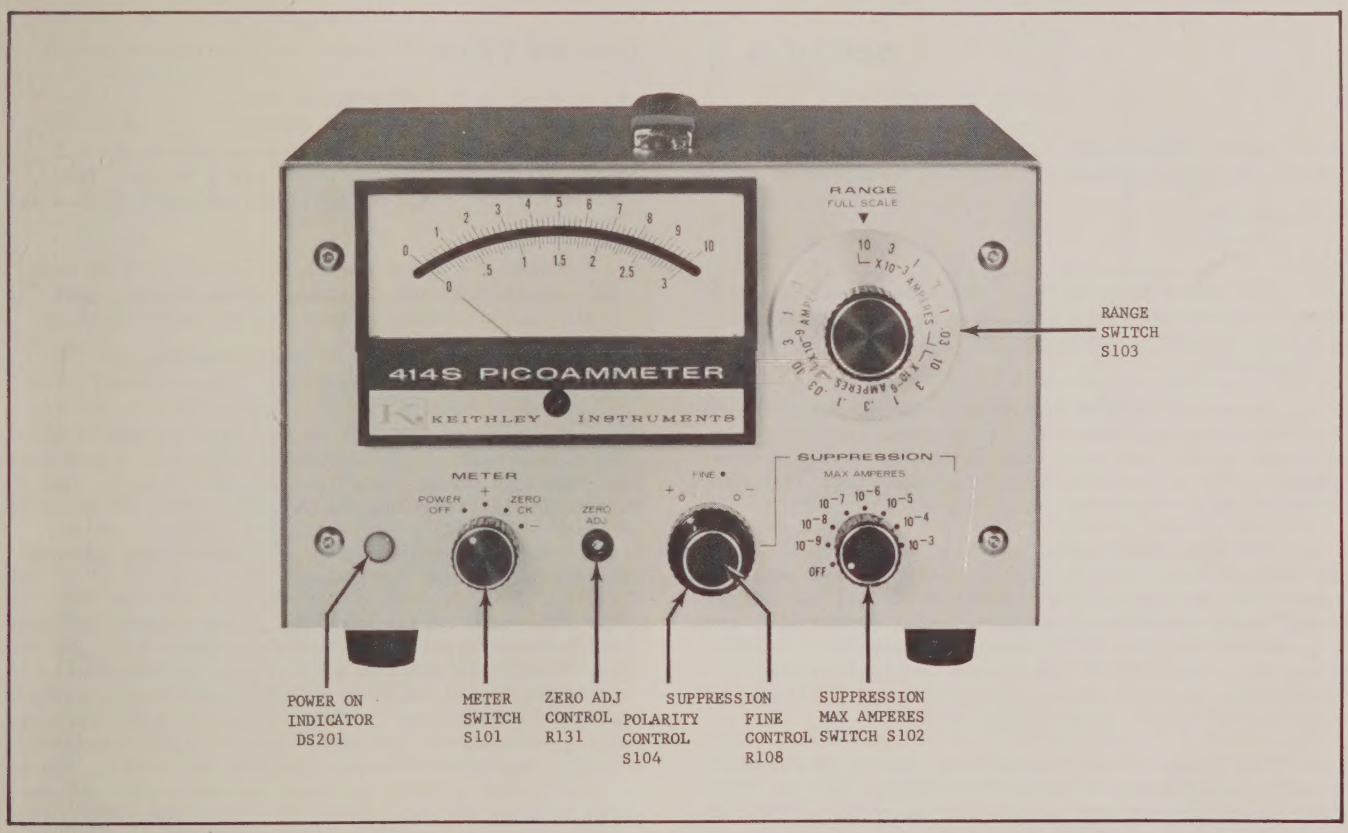


FIGURE 1. Front Panel Controls.

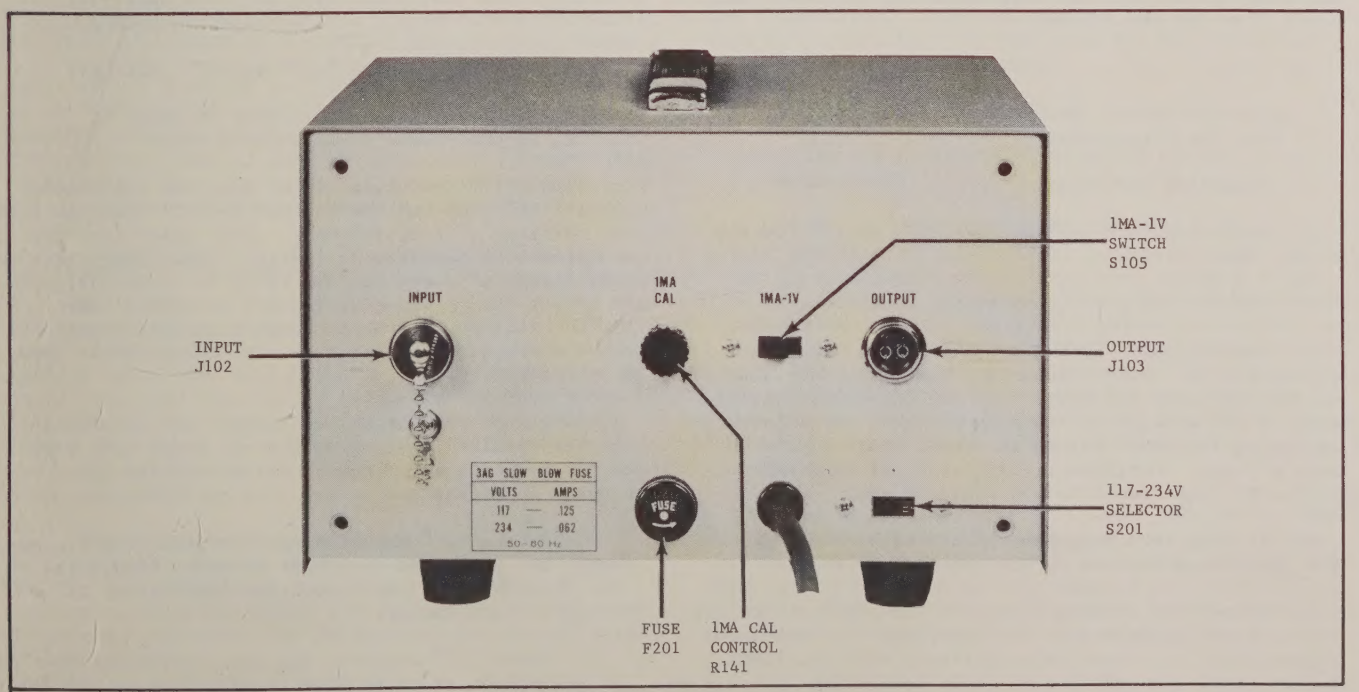


FIGURE 2. Rear Panel Controls.

SECTION 2. OPERATION

2-1. INPUT CONNECTIONS. Use the following precautions when using the Picoammeter on the more sensitive ranges.

a. The INPUT Receptacle of the Model 414S is a Teflon-insulated UHF connector. The center terminal is the high impedance terminal, and the outer shield is case ground.

b. Carefully shield the input connection and the current source being measured, since power line frequencies are well within the pass band of the Picoammeter on all ranges. Unless shielding is thorough, pickup may cause definite meter disturbances.

c. Use high resistance, low-loss materials — such as polyethylene, polystyrene or Teflon — for insulation. The insulation resistance of test leads and fixtures should be several orders of magnitude higher than the source resistance. Excessive leakage will reduce accuracy. Any coaxial cable used should be a low-noise type which employs a graphite coating between the dielectric and the surrounding shield braid.

d. Any change in the capacitance of the measuring circuit to ground will cause disturbances in the reading, especially on the more sensitive ranges. Make the measuring setup as rigid as possible, and tie down connecting cables to prevent their movement. If a continuous vibration is present, it may appear at the output as a sinusoidal signal and other precautions may be necessary to isolate the instrument and the connecting cable from the vibration.

NOTE

Keep the shield cap on the INPUT Receptacle when the Picoammeter is not in a circuit.

2-2. OPERATING PROCEDURES.

a. Check the fuse and the 117-234 V Switch for the proper line voltage.

b. Connect the power cord to the power source.

c. Set the RANGE Switch to 10^{-2} ampere, the METER Switch to (+). Within seconds the meter needle should read zero. Zero the meter with the ZERO ADJ. Control. After a few moments increase the current sensitivity by advancing the RANGE Switch in decade steps to the 10^{-10} ampere range. Continue zeroing with the ZERO ADJ Control. The instrument is now ready to use.

d. If long term measurements are to be made, allow the instrument to warm up for at least 10 minutes.

e. Attach the current source to the INPUT Receptacle and turn the METER Switch to the polarity of the input signal, + or -. Increase sensitivity with the RANGE Switch until the greatest on scale deflection is achieved.

1. When the RANGE Switch is set to 10, 1, 0.1, etc. positions, use the upper meter scale. Full scale current range is equal to the RANGE Switch setting.

2. When the RANGE Switch is set to 3, 0.3, 0.03, etc. positions, use the lower meter scale. Full scale current range is equal to the RANGE Switch setting.

2-3. MEASUREMENT CONSIDERATIONS.

a. The Picoammeter employs the fast method of current measurement — the measuring resistor is between the amplifier input and output in the feedback loop. This method largely neutralizes the effect of input capacity and greatly increases the response speed. Also, the input voltage drop is reduced to a maximum of one millivolt on any range.

b. Rise time varies with the current range and the input capacity (see specifications, Table 1). The rise time, though, is not affected with up to 500 picofarads across the input; however, it is better to place the Picoammeter nearer the current source than to the data reading instrument. Transmitting the input signal through long cables — with greater than 500 picofarads of capacitance — will increase response time and meter noise.

c. The internal resistance of the unknown source should not be less than the reciprocal of the current range being used, otherwise the zero stability will be affected. The instrument will still be operable, however, but the stability will be degraded by the amount given by equation 1.

$$\text{Stability} = 0.5\%/\text{week} \times (R_s + R_f)/R_s \quad \text{Equation 1.}$$

where R_f is the feedback resistance in ohms;
R_s is the source resistance in ohms.

For example, if the source to be measured has a resistance of 10^5 ohms and the current is 10^{-6} then the feedback resistor will be 10^6 ohms. This means that the gain of the Picoammeter is $10^6/10^5 = 10$. Then the zero stability of .5%/week will be .5% X 10 = 5%/week, and the offset due to temperature will be .05% X 10 = .5%/^{o}C. This is the reason that it is advantageous to have the source resistance at least equal to the feedback resistor.

d. Overload Protection. A unique circuit provides complete overload protection for the Model 414S without compromising the features of the MOS FET input. Recovery is instantaneous for most overloads.

1. At the 10^{-6} ampere range and below the Picoammeter can withstand overloads of up to 1000 volts for 3 seconds and continuous overloads of up to 600 volts without damage.

2. Above 10^{-6} amperes, the max. continuous overload is a function of rated power dissapation in the resistor

TABLE 4.
Allowable Overloads on Ranges Above 10^{-6} Ampere.

Range	Max. Continuous Voltage Overload	Max. Continuous Current Overload
10^{-5} A	300 V	1 mA
10^{-4} A	120 V	4 mA
10^{-3} A	30 V	10 mA
10^{-2} A	12 V	40 mA

3. For maximum protection, use a Keithley Model 240A Voltage Supply, or some other 10 milliampere current limited supply, in combination with the Picoammeter.

2-4. RECORDER OUTPUTS.

a. For recording with the Model 414S, use the Keithley Model 370 Recorder for ease, economy, versatility and performance. The Model 370 is a pen recorder with 10 chart speeds and 1% linearity. The Model 370's input cable has a connector which mates directly with the OUTPUT Connector on the Picoammeter; this avoids interface problems often encountered between a measuring instrument and a recorder. The Picoammeter output, when set to the 1 mA position, will drive the 370; no preamplifier is needed. No special wiring is required.

b. Other recorders, oscilloscopes and similar instruments can be used with the Model 414S. The Picoammeter has two outputs, ±1 volt and ±1 milliampere, to amplify signals for recorders, oscilloscopes and similar instruments. These can be used on all ranges.

c. 1-Volt Output. Connect oscilloscopes and pen recorder amplifiers to the OUTPUT Receptacle. Pin no. 1 is the high terminal and pin no. 2 is ground. Set the 1 mA - 1 V Switch to 1 V. The Picoammeter output is now ±1 volt for full scale meter deflection on any range. Internal resistance is approximately 1 kilohm. Noise is less than 1% peak-to-peak of full scale. The METER Switch does not reverse the output polarity. Output polarity is always opposite input polarity.

d. 1-Milliampere Output. Connect 1-milliampere instruments to the OUTPUT Receptacle. Pin no. 1 is the high terminal. Set the 1 mA - 1 V Switch to 1 mA. The output is approximately 1 milliampere for full-scale meter deflection on any range. For exact output, apply a known full scale signal to the Picoammeter and adjust the 1 mA CAL Control until the recorder reads full scale. Check the recorder and meter zero and repeat adjustment if necessary. The METER Switch does not reverse the output polarity which is always opposite input polarity.

e. For servo rebalance recorders, use a divider across the Picoammeter OUTPUT Receptacle. See Figure 3. Set the OUTPUT Switch to 1 mA. Use the 1 mA CAL Control to trim the output for full-scale recorder deflections. Operation is the same as for current outputs.

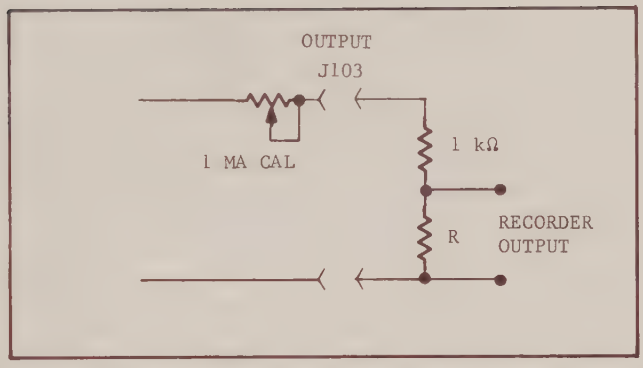


FIGURE 3. Divider Circuits Across Picoammeter Output for Driving 50 and 100-Millivolt Recorders.

2-5. 234-VOLT OPERATION. The instrument is shipped for use with a 117-volt power source unless otherwise ordered. To convert the Picoammeter for 234-volt sources, use a screwdriver to change the slide switch on the back panel to the 234-volt position. Change the fuse from 0.125 ampere to .062 ampere. No other adjustment is necessary. To switch from 234 to 117-volt operation, reverse the procedures.

2-6. SUPPRESSION CURRENT OPERATION. The Model 414S provides up to 100 times current suppression over a range of 10^{-3} to 10^{-9} ampere. By suppressing background currents, variations as small as 1% in a larger signal can be displayed full scale. Currents of either polarity may be suppressed.

a. Suppression is achieved by applying a current of opposite polarity to the input current at the input of the Picoammeter. This suppression current is obtained from well regulated ±12 volt supplies in conjunction with resistors.

b. Use the suppression circuit as follows:

1. Set the SUPPRESSION, Polarity Control to + or -, as necessary.

2. Set the SUPPRESSION, MAX AMPERES Switch to the same sensitivity as the RANGE Switch setting. Adjust the 10-turn FINE Control for a zero reading on the meter. Increase the sensitivity of the RANGE Switch one decade. Adjust the FINE Control for a zero reading. This is ten times current suppression. To obtain 100 times suppression, increase the sensitivity of the RANGE Switch one more decade and zero the meter. In this mode the Model 414S is able to detect fluctuations of 1% of full scale of the suppression current.

c. When using 100 times full scale suppression the resistor used in the suppression circuit will be one-tenth the value of the current measuring resistor. In this mode the zero drift and temperature drift will be approximately ten times greater than normal. (See the discussion in paragraph 2-3c for explanation).

SECTION 3. CIRCUIT DESCRIPTION

3-1. GENERAL. The Keithley Model 414S is a linear dc amplifier with a full scale sensitivity of either 1 or 3 volts. By using the front panel controls, shunt resistors are selected to make measurements over a total of 17 current ranges. (Refer to schematic diagram 22394E for circuit designations.)

3-2. AMMETER OPERATION.

a. The amplifier has matched insulated-gate field-effect input transistors followed by a differential transistor stage, a transistor amplifier and a transistor output stage. Figure 4 shows the simplified circuit for the Picoammeter.

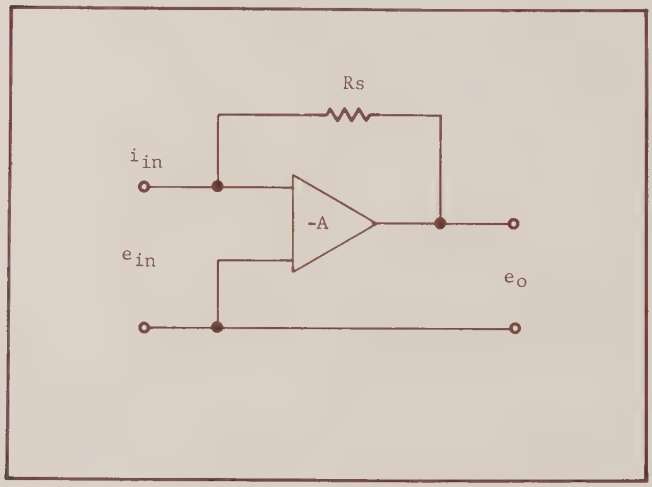


FIGURE 4. Simplified Diagram for Ammeter Circuit.

b. If it is assumed that the input voltage drop, e_{in}, is negligible, then all the input current, i_{in}, flows through the measuring resistor, R_s, and

$$e_o = -i_{in} R_s. \qquad \text{Equation 2.}$$

But the output voltage, e_o, is also equal to the input voltage times the amplifier gain.

$$e_o = -A\, e_{in}. \qquad \text{Equation 3.}$$

Therefore, from equations 2 and 3 we get

$$A\, e_{in} = i_{in} R_s. \qquad \text{Equation 4.}$$

From whence,

$$e_{in}/i_{in} = R_s/A. \qquad \text{Equation 5.}$$

where e_{in}/i_{in} is the effective input resistance.

Thus, the input voltage drop is kept at a small fraction, 1/A, of the output voltage, and the effective input resistance is 1/A of the measuring resistor.

3-3. AMMETER CIRCUIT.

a. Two balanced insulated-gate field-effect transistors, Q101 and Q102, are used for the amplifier input. Resistors R125 and R126 and circuit designation 21850B (see schematic) protect the gate of transistor Q101, the active field-effect transistor, from overloads. The gate of Q102 is returned to amplifier ground.

b. Turning the METER Switch to ZERO CK position places a short from the input to the output and zeroes the instrument.

c. A differential amplifier stage, transistors Q103 and Q104, drives an amplifier stage, transistor Q105, which in turn drives the output emitter follower, transistor Q106.

d. Two zero controls are used. The Coarse Zero Control, R128 varies the source voltage of transistor Q101 with respect to transistor Q102. The ZERO ADJ Control, R131, varies the drain voltage of transistor Q101 with respect to transistor Q102.

e. The DC Bal Potentiometer, R127, sets the drain current through transistors Q101 and Q102 by varying the source bias.

f. The voltage drop across R123 plus R124, or R124 alone, determines the full scale sensitivity of the amplifier — either 3 volts from 10^{-2} through 3×10^{-8} and 3×10^{-9} and 3×10^{-10} or 1 volt on 10^{-8}, 10^{-9} and 10^{-10} ranges. Applying a full scale signal to the input causes a 1 milliampere current to flow through R123 and R124. The meter is connected across the 3-volt output. Resistors R138 and R139 set the meter current.

g. The full scale current sensitivity is determined by the range resistors R109 through R122 in combination with resistors R123 and R124. The current measuring resistor is connected in the feedback loop. This configuration increases the response speed by minimizing the effects of input capacity. It also reduces the input voltage drop to less than 1 millivolt.

h. The 1 volt recorder output is derived from 1 milliampere flowing through resistor R143. In the 1 milliampere output mode an external load is substituted for R143. Potentiometer R141 varies the current to the external load.

3-4. POWER SUPPLIES. The Model 414S has positive and negative supplies, which provide power to the amplifier and output.

a. +25 and +12 volt supply. The power supplied from secondary of transformer T201 is rectified by diodes D201 and D203 and filtered by capacitor C201 to provide +25 volts for the output. Zener diode, D205, is used to provide a regulated +11 volts for the amplifier.

b. -25 and -12 volt supply. This supply uses diodes D202 and D204, capacitor C202 and zener D206 to perform the same functions as the positive supply.

3-5. SUPPRESSION CIRCUIT. The suppression is obtained from two well regulated supplies in conjunction with decade values of resistors and a ten-turn potentiometer. Suppression is obtained by placing one of various resistors between the input of the ammeter and a power supply. The magnitude of the suppression current is determined by the setting of the SUPPRESSION, FINE Potentiometer, R108. Suppression current polarity is determined by which power supply the potentiometer is connected to.

a. +12 volt Supply.

1. The secondary of the line transformer, T201, is rectified by diodes D201 and D203 and filtered by C201 and applied to the collector of the series pass transistor, Q201. Resistor R202 and the zener diode, D205, form a bootstrap circuit to supply starting current. The positive supply does not use a zener directly for a reference element, but uses the -12 volt supply as a reference.

2. The base of Q206, connected as one half of a differential amplifier, is returned to ground. The base of the other transistor, Q207, is connected to the junction of two equal resistors, R211 and R212, which are connected between the outputs of the ± supplies. If the feedback to the series pass transistor is of the proper phase, then the base of transistor Q207 must be approximately zero volts to maintain proper operating conditions. For this to be so, the output of the + supply must go to the same magnitude of the negative supply (12 volts).

3. The collector of Q206 is attached to the base of Q204, one-half of the differential pair formed with Q205. The base of Q205 is returned to a reference voltage at the junction of the resistors R207 and R208 connected between +12 and ground.

4. The collector of Q204 drives the base of the Darlington amplifier, Q202, which drives the base of the series pass transistor, Q201.

5. Transistor Q203 acts as an overload protection by sensing the voltage drop across resistor R206. On overload the voltage drop across R206 causes Q203 to turn on which clamps the base of Q202 to the output, thus limiting the maximum current drain.

b. -12 Volt Supply.

1. The secondary of transformer T201 is rectified by diodes D202 and D204, filtered by capacitor C205 and applied to the collector of the series pass transistor, Q208. Resistor R213 and zener diode D206 form a bootstrap circuit to supply starting current.

2. The base of Q212, one-half of a differential amplifier, is referenced to zener diode D208. The base of Q213 is connected to the center tap of potentiometer R222 which sets the value of the output voltage.

3. The collector of Q212 is attached to the base of amplifier Q211 which drives the base of the Darlington amplifier, Q209, which drives the base of the series pass transistor, Q208.

4. Transistor Q210 acts as an overload protection as described in paragraph 5 above.

c. Current Suppression.

1. The Potentiometer, R108, is connected to either the + or - supply by S104. The center tap of R108 is attached to one of the current suppression resistors, R101 through R107, selected by S102. The other end of the resistor is attached to the input of the ammeter.

2. The magnitude of the suppression is determined by the setting of the potentiometer which varies the voltage to the resistor.

SECTION 4. SERVICING

4-1. GENERAL. Section 4 contains the maintenance and troubleshooting procedures for the Model 414S Picoammeter. Follow these procedures as closely as possible to maintain the performance of the instrument.

4-2. SERVICING SCHEDULE. The value of the high-megohm resistors, R121 and R122, should be checked approximately every six months for specified accuracy. Except for this the Model 414S requires no periodic maintenance beyond the normal care required of high-quality electronic equipment.

4-3. PARTS REPLACEMENT.

a. The Replaceable Parts List in Section 7 describes the electrical components of the Picoammeter. Replace components only as necessary. Use only reliable replacements which meet the specifications.

b. The MOS FET input transistors, Q101 and Q102, are specially selected and matched; order only as a plug-in unit, part number 23734A, from Keithley Instruments, Inc.

4-4. TROUBLESHOOTING.

a. The Procedures which follow give instructions for repairing troubles which might occur in Model 414S. Use the procedures outlined and use only specified replacement parts. Table 5 lists equipment recommended for troubleshooting. If the trouble cannot be readily located or repaired, contact Keithley Instruments, Inc., or its representative.

b. Table 6 contains the more common troubles which might occur. If the repairs indicated in the table do not clear up the trouble, find the difficulty through a circuit-by-circuit check, such as given in paragraph 4-5. Refer to circuit description in Section 3 to find the more critical components and to determine their function in the circuit. The complete circuit schematic, 22394E, is in Section 7.

4-5. PROCEDURES TO GUIDE TROUBLESHOOTING.

a. If the instrument will not operate, check the power supplies. The typical voltage values, given on the schematic, are referenced to chassis ground. Zero the Model 414S meter and make measurements with a Model 153.

b. At times, the meter will not zero on any range with the METER Switch in the ZERO CK position. If this occurs, adjust the front panel ZERO ADJ Control or, if necessary, the Coarse Zero Potentiometer, R128, located on the PC board. If this does not work, inspect all PC boards for a possible break in the tapes. If these appear all right proceed with step c.

TABLE 5.
Equipment Recommended for Model 414S Troubleshooting and Calibration. Use these instruments or their equivalents.

Instruments	Use
Keithley Model 163 Digital Voltmeter, ±0.1% of reading, 10 megohm input resistance.	General calibration.
Hewlett Packard 202A Function Generator	Rise time check.
Keithley Instruments Model 153 Microvolt-Ammeter, 10 μV to 1000 V, 200 MΩ input resistance, ±1% accuracy, float ±500 volts off ground.	General circuit checking.
Keithley Instruments Model 261 Picoampere Source; 10^{-14} to 10^{-4} ampere.	Source to calibrate current.
Keithley Instruments Model 370 Recorder	Monitor drift.
Keithley Instruments Model 515A Megohm Bridge.	Verify high megohm resistors in Range Switch.
Keithley Instruments Model 662 Guarded Differential Voltmeter; 100 μV to 500 V, ±0.01%.	Calibrate meter zero.
Shielded resistors of different values, and shielded 50 pF and 500 pF polystyrene capacitors.	Rise time check.
Tektronix Model 561A Oscilloscope	Noise and rise time check.

TABLE 6. Model 414S Troubleshooting.

Difficulty	Probable Cause	Solution
Excessive zero offset	Input transistors may be defective	Check Q101 and Q102; replace if faulty.
	Power supply voltage low	Check power supply
Excessive offset current	Excessive temperature fluctuations or defective input transistors	Check Q101 and Q102; replace if faulty.
Cannot zero on any range	Refer to paragraph 4-5.	Refer to paragraph 4-5.
Meter off scale on one of range settings	Faulty range resistor	Check resistor; replace if faulty.
One of ranges out of specification	Defective range resistor	Check resistor; replace if faulty.
Excessive drift on all ranges when using current suppression.	Power supplies drifting	Check power supplies. Refer to paragraph 4-5d.
Excessive noise when using current suppression	Power supplies noisy or not regulating	See paragraph 4-5d.
Excessive drift on one range when using suppression	One of suppression resistors drifting	Check resistor; replace if faulty.

c. Amplifier.

1. To check the amplifier, disconnect the feedback loop by removing Q106, D102, D105 and R129 from the PC board. Check diodes D102 and D105.

2. Connect a Model 153 between the bases of Q103 and Q104. Adjust Coarse Zero Potentiometer, R120, and front panel ZERO ADJ Control for a null (it may be difficult to reach a steady null; however, it is sufficient to be able to swing through zero in a smooth manner). If this is not possible, remove Q103 and Q104 from the circuit and repeat the same process. If null can now be reached, replace Q103 and Q104. If it cannot be reached, Q101 and Q102 are faulty.

3. Check the next stage, Q105, by placing a Model 153 from the collector end of R128 to ground. Adjust the Model 414S Zero Controls for a null. If this cannot be accomplished, check D101 for a possible open by shorting it with a clip lead. If null can now be reached, D101 is open and should be replaced. If null cannot be reached, replace Q105.

4. If null can now be attained at the collector of Q105, the trouble is in the output stage and Q106 should be replaced. If this does not cure the trouble, carefully check all the diodes associated with the output stage - D102, D103, D104 and D105.

d. Power Supplies.

1. As a preliminary check, measure the input voltage to the series pass transistors, Q201 and Q208. If they are within ±10% of nominal value, proceed as below.

2. Check for a possible short on the output by measuring the drop across resistors R206 and R215. If the drop is greater than .5 or .6 volt then it is likely that a short exists.

NOTE

An important point to remember is that the +12 volt supply derives its regulation from the -12 volt supply. Therefore, if the -12 volt supply is not working, the +12 volts will not regulate. Thus, the -12 volt supply should always be checked first.

3. If no short exists the faulty component can usually be isolated by making a point-by-point check of the voltages indicated on the schematic.

SECTION 5. CALIBRATION

5-1. GENERAL.

a. The following procedures are recommended for calibrating the Model 414S. Use the equipment recommended in Table 5. If proper facilities are not available or if difficulty is encountered, contact Keithley Instruments, Inc., or its representatives to arrange for factory calibration.

b. If the Model 414S is not within specifications after the calibration, follow the troubleshooting procedures or contact Keithley Instruments, Inc., or its representatives.

5-2. PRELIMINARY PROCEDURES.

a. Make sure the 1 MA - 1 V and 117-234 V Switches on the rear panel are set to 1V and 117V respectively. Set the Front Panel Controls as follows:

RANGE Switch	10 MILLIAMPERES
METER Switch	POWER OFF
ZERO ADJ. Control	Mid-range.
SUPPRESSION (MAX)	OFF

b. Set the DC Bal Potentiometer, R127, Coarse Zero Potentiometer, R128, and Meter Cal. Potentiometer, R139, near mid-range.

c. Zero the meter with the Mechanical Zero Control.

d. Plug the Model 414S into a 117 volt source and set the METER Switch to ZERO CK.

1. If the Model 414S is operative, then the meter should read on scale for either polarity (+ or -). Adjust the Coarse Zero Potentiometer for a zero indication on the meter.

2. If the Coarse Zero Potentiometer, R128, can not zero the meter, check for a shorted heat sink on the MOS FET transistors, Q101 and Q102. The two halves of the heat sink must be insulated in order for the Coarse Zero potentiometer to function properly.

TABLE 7. Model 414S Internal Controls

The Table lists all internal controls, the figure picturing the location and the paragraph describing the adjustment.

Control	Circuit Desig.	Fig. Ref.	Refer to Paragraph
DC Bal.	R127	7	5-2, 5-4
Coarse Zero	R128	7	5-2, 5-4
Meter Cal	R139	7	5-2, 5-6
±12V Adj	R222	7	5-3

5-3. POWER SUPPLY CHECK. (See Figure 6 for test points for the Power Supplies.)

a. Check the positive and then the negative 25 volt supply by connecting the Model 163 across capacitors C201 and C202 respectively (Figure 6). The voltage should be plus and minus 25 volts ±2 volts respectively. The ripple in each case should be less than 3 volts peak-to-peak.

NOTE

For all these power supply checks make sure the Model 163 is connected between ground and the test points (Figure 6).

b. Check the positive and then the negative 25 volt supply by connecting the Model 163 across capacitors C201 and C205 respectively (Figure 6). The voltage should be plus and minus 26 volts ±2 volts respectively. The ripple in each case should be less than 3 volts peak-to-peak.

c. Check the positive and then the negative 12 volt supply by connecting the Model 163 across capacitors C204 and C207 respectively. Adjust the -12 volt supply to -12.0 volts with the ±12 V Adj. potentiometer, R222. The voltage for the +12 volt supply should be +12 volts ±0.2 volt. The ripple in each case should be less than 2mV peak-to-peak.

d. Monitor the plus and minus 12 volt supplies as the line voltage is changed from 105 volts ac to 125 volts ac. The voltage change of the plus and minus 12 volt supplies should be less than 3 mV.

e. Turn the Model 414S off and prepare the Picoammeter for 234 volt, 50 Hz operation. Plug the Model 414S into a 220 volt ac, 50 cycle line and check the positive and negative 25 volt supplies per paragraph 5-3b above. The same readings as in subparagraph b above should be obtained except that an additional 1 volt tolerance should be allowed for each 10 volt difference between 234 volts ac and the actual line voltage.

5-4. MOS FET CURRENT ADJUST.

a. Set the Picoammeter RANGE Switch to 10 $\times 10^{-3}$ amperes and the METER Switch to ZERO CK.

b. Set the front panel ZERO ADJ. Control to approximately mid-range and adjust the Coarse Zero Potentiometer, R128, for a zero indication on the meter.

c. Connect the Model 163 DVM across resistor R130 and adjust the DC BAL Potentiometer, R127, for an indication of -5.4 volts ±0.2 volt.

5-5. OFFSET AND NOISE CHECKS.

a. To check the offset:

1. Set the Picoammeter RANGE Switch to 10 x 10^{-3} AMPERES and the METER Switch to ZERO CK. Cap the INPUT Receptacle and connect the Model 414S to the Model 163 DVM.

NOTE

When checking the offset noise, make sure the Model 414S cover is on.

2. If necessary, adjust the ZERO ADJ. Control for zero volts at the output.

3. Set the RANGE Switch to .1 x 10^{-9}A. Make sure that the output remains at zero volts, adjusting the front panel ZERO ADJ. Control if necessary.

4. Set the METER Switch to +. The output should remain within ±10 millivolts.

b. To check the noise:

1. Connect the Model 414S OUTPUT Receptacle to the Model 561A Oscilloscope.

2. Set the METER Switch to + and vary the line voltage from 105 volts ac to 125 volts ac. The output noise should be less than 10 millivolts peak-to-peak on all ranges.

5-6. METER AND 1MA OUTPUT CALIBRATION.

a. Set the RANGE Switch to 1 MICROAMPERE. Connect the Model 261 Picoampere Source to the Model 414S INPUT Receptacle and connect the Model 163 DVM to the OUTPUT Receptacle.

b. Set the Model 414S METER Switch to + and apply 10^{-6} ampere with the Model 261. If necessary, adjust the ZERO ADJ. Control for exactly 1.000 volt at the output.

c. Adjust the Meter Cal Potentiometer, R139, for full scale meter deflection.

d. Load the Model 414S output with a 1.5 kilohm resistor and set the 1 V - 1 MA Switch to 1 MA.

e. Adjust the rear panel 1 MA CAL Control and note that the output voltage can be adjusted at least 0.1 volt either side of 1.5 volts.

f. Remove the 1.5 kilohm load and set the 1 V - 1 MA Switch to 1 V.

g. Set the METER Switch to ZERO CK and re-zero the output if necessary.

5-7. RANGE ACCURACY CHECK.

a. Connect the Model 414S INPUT Receptacle to the Model 261. Connect the OUTPUT Receptacle to the Model 163 DVM.

b. Check the full-scale accuracy of all positions on the RANGE Switch. Check both positive and negative inputs to ensure proper operation of both polarities at various current input levels. Check the accuracy of the 10 x 10^{-3}A through the 10 x 10^{-9}A ranges to ±2% of full scale at the output (1.0 volt ±20 millivolts). Check the accuracy of the 3 x 10^{-9}A through the .1 x 10^{-9}A ranges to ±4% of full scale at the output (1.0 volt ±40 millivolts).

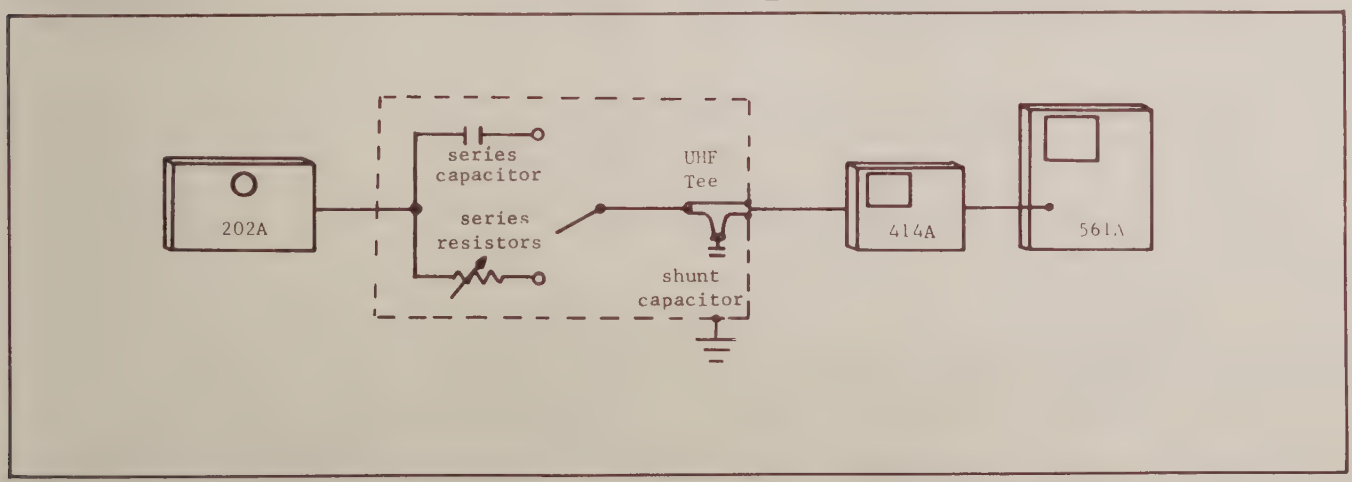


FIGURE 5. Test Set-up for Model 414S Rise Time Check on all ranges. Be sure to properly shield the series resistors or capacitor, UHF-Tee and the Shunt Capacitor.

5-8. RISE TIME CHECK. To check the rise time of the Model 414S requires two different test set-ups. The first set-up is for checking the rise times on the 1×10^{-3}A through 10×10^{-9}A ranges. The second set-up is for checking the rise times on the ranges 1×10^{-9}A and below.

a. 1×10^{-3}A through 10×10^{-9}A ranges. Set the test fixture as illustrated in Figure 5.

1. Equipment used (Refer to Table 5): The Model 202A Function Generator, six shielded resistors ranging in value from 3 kilohms to 300 megohms (See Table 8), a UHF Tee connector, a 500 pF polystyrene shunt capacitor, the Model 414S and the Model 561A Oscilloscope. The oscilloscope used must be dc coupled.

TABLE 8. Model 414S Rise Time Check for 1×10^{-3}A through 10×10^{-9}A Ranges. The Table gives the Model 414S RANGE Switch settings, the Function Generator frequency settings, the series resistor used for each RANGE Switch setting, and the maximum allowable rise time.

Model 414S RANGE Switch Setting	Series Resistors	Function Generator Frequency (Hz)	Maximum Rise Time (milliseconds)
1×10^{-3}A	3 kΩ	250	less than 1
$.1 \times 10^{-3}$A	30 kΩ	250	less than 1
10×10^{-6}A	300 kΩ	250	less than 1
1×10^{-6}A	3 MΩ	2.5	50
$.1 \times 10^{-6}$A	30 MΩ	2.5	90
10×10^{-9}A	300 MΩ	2.5	130

2. Procedures:

a) Apply a square wave from the Model 202A Function Generator across the selected series resistor, through the UHF Tee to the Model 414S INPUT Receptacle. Observe the output of the Model 414S with the Model 561A.

b) For each Model 414S range, use the Model 202A frequency setting and the series resistor indicated in Table 8.

c) Adjust the Model 202A amplitude control as needed to obtain 2 volts peak-to-peak at the Model 414S output. Check the 10 - 90% rise time to the figures shown in Table 8.

b. 1×10^{-9}A and $.1 \times 10^{-9}$A ranges. Set this test fixture up as illustrated in Figure 5, except that a shielded 50 pF polystyrene capacitor should be substituted for the series resistors between the Function Generator and the UHF Tee.

1. Equipment Used: This test set-up uses the same equipment of the previous set-up with the exception of the 50 pF polystyrene capacitor. The capacitor in this set-up serves a similar function as the series resistors in the previous test set-up.

2. Procedures:

a) Apply a triangular wave from the Model 202A across the capacitor, through the UHF Tee to the Model 414S INPUT Receptacle. Monitor the Model 414S output with the Model 561A. Use the proper Model 202A frequency setting as indicated in Table 9.

b) Adjust the Model 202A amplitude control as needed to obtain 2 volts peak-to-peak at the Model 414S output. Check the 10 - 90% rise time to the figures shown in Table 9.

TABLE 9. Model 414A Rise Time Check for 1×10^{-9}A and $.1 \times 10^{-9}$A Ranges. The Table gives the Model 414S RANGE Switch settings, the Function Generator frequency settings, and the maximum allowable rise time.

Model 414S RANGE Switch Setting	Function Generator Frequency (Hz)	Maximum Rise Time (milliseconds)
1×10^{-9}	1.0	150
$.1 \times 10^{-9}$	0.25	750

5-9. DRIFT VERIFICATION.

a. Shunt the Input of the Model 414S with a 10-kilohm resistor with the RANGE Switch set to 1×10^{-6}A and the METER Switch set to + or -, as necessary. Using the shunt increases the sensitivity 100 times.

NOTE

While doing the drift run make sure the Model 414S cover is on.

b. Connect the Model 370 Recorder to the Model 414S. Set the Recorder attenuator to 1 volt (10 millivolts drift full scale) or 0.3 volts (3 mV full scale).

c. Set the METER Switch to + and adjust the ZERO ADJ Control for near zero volts output. The ZERO ADJ Control is very sensitive with the sensitivity increased 100 times. Set the METER Switch to - if the drift is negative.

d. After a 10-minute warm-up, the Model 414S may drift 700 microvolts per 24 hours plus or minus 500 microvolts per °C change in temperature.

e. In some cases, the 24-hour drift may appear marginal or it may be slightly out of specification due to a steep drift slope during the early part of the drift. If this is so, it may be desired to continue the drift for an additional 24 hours and calculate a weeks drift as follows:

1. Multiply the drift during second 24-hour period times 6 and add the drift noted during the first 24-hour period.

2. Total drift should not exceed 5 mV.

5-10. SUPPRESSION CHECK.

a. Cap the input of the Model 414S and connect the output to the Model 163.

b. Set the front panel controls as follows:

RANGE Switch	1×10^{-3}
METER Switch	(+)
ZERO ADJ. Control	Mid-range
SUPPRESSION, MAX AMPERES Switch	10^{-3}
SUPPRESSION, Polarity Control	(-)

c. Adjust the SUPPRESSION, FINE Control for a full scale meter deflection. Monitor the output voltage on the 163 and adjust the SUPPRESSION, FINE Control for maximum suppression. At maximum suppression, the output voltage observed on the Model 163 should be greater than 1.1 volts (10% over-range).

d. Set the front panel controls as follows:

RANGE Switch	$.1 \times 10^{-3}$
METER Switch	(+)
ZERO ADJ. Control	Mid-range
SUPPRESSION, MAX AMPERES Switch	10^{-4}
SUPPRESSION, Polarity Control	(-)

e. Adjust the SUPPRESSION, FINE Control for a full scale meter deflection.

f. Using the method described in paragraph b above, test the suppression for each setting of the RANGE Switch, using corresponding settings of the SUPPRESSION, MAX AMPERES Switch. The output voltage noted on the Model 163 should not vary more than $\pm$4%.

g. Then, set the front panel controls as follows:

RANGE Switch	1×10^{-3}
METER Switch	(-)
ZERO ADJ. Control	Mid-range
SUPPRESSION, MAX AMPERES Switch	10^{-3}
SUPPRESSION, Polarity Control	(+)

Repeat the procedures outlined in sub-paragraph c, d and e above.

h. Set the front panel controls as follows:

RANGE Switch	10×10^{-9}
METER Switch	(+)
ZERO ADJ. Control	Mid-range
SUPPRESSION, MAX AMPERES Switch	OFF
SUPPRESSION, Polarity Control	(+)

With the Model 261 apply 10^{-8} ampere to the Model 414S input. Monitor the output with a 5 mV/div ac coupled Model 561A oscilloscope.

i. Set the SUPPRESSION, MAX AMPERES Switch to 10^{-8} and adjust the SUPPRESSION, FINE Control to buck out the input signal as the RANGE Switch is changed to $.1 \times 10^{-9}$.

j. Meter noise should be less than 2% (one minor division). Output noise observed on the oscilloscope should be less than 10 mV peak-to-peak, excluding any low frequency component.

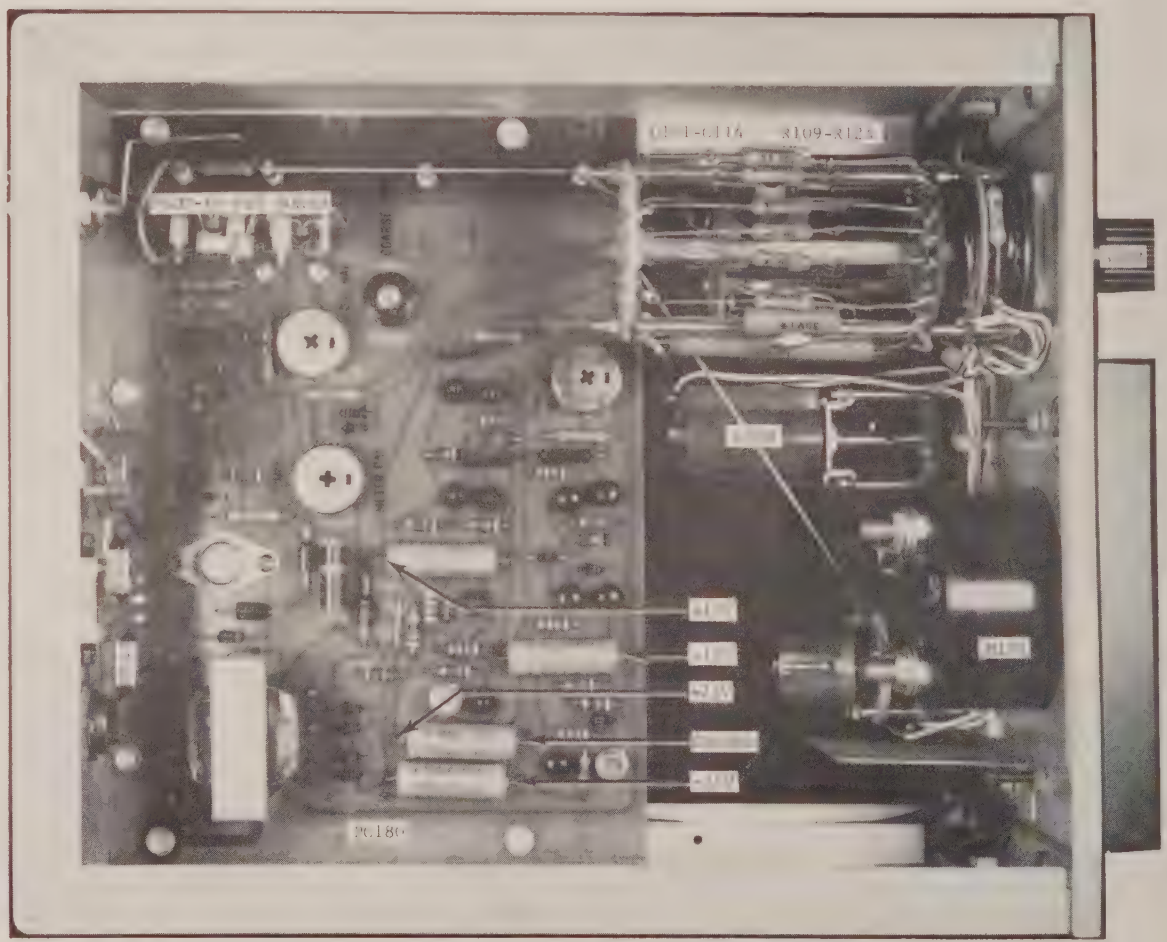


FIGURE 6. Chassis, Top View.

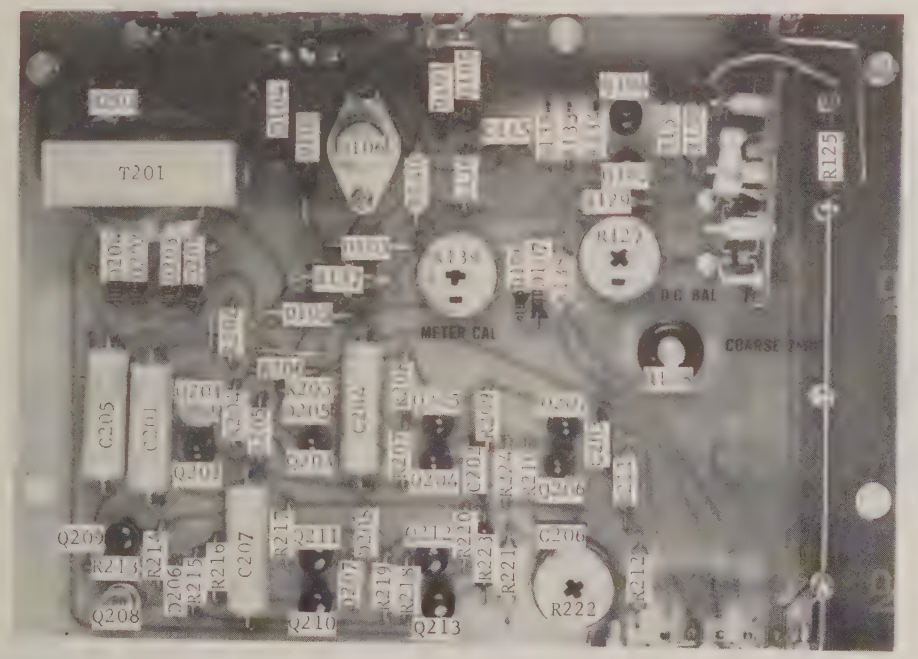


FIGURE 7. Component Layout, PC180.

SECTION 6. ACCESSORIES

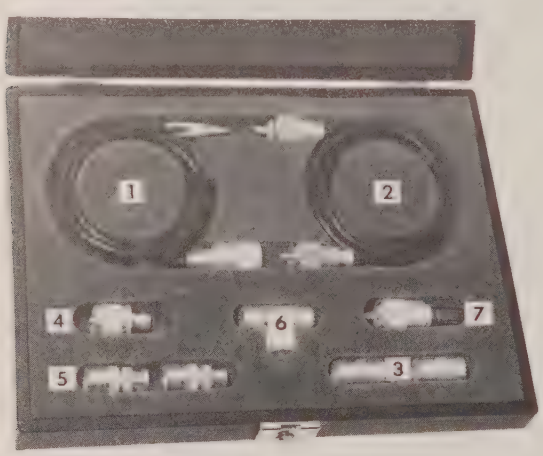
6-1. GENERAL. The following Keithley accessories can be used with the Model 414S to provide additional convenience and versatility.

6-2. OPERATING INSTRUCTIONS. A separate Instruction Manual is supplied with each accessory giving complete operating information.

Model 6106 Electrometer Connection Kit

Description:

The Model 6106 contains a group of the most useful leads and adpaters for low current measurements. All components are housed in a rugged carrying case with individual compartments.



Parts List:

Description	Item No.	Keithley Part No.
Cable, 30", UHF to clips	1	19072C
Cable, 24", UHF to UHF	2	18265C
Connector, UHF to UHF	3	CS-5
Adaptor, UHF to BNC	4	CS-115
Adaptor, UHF to BNC	5	CS-172
Adaptor Tee, UHF to UHF	6	CS-171
Adaptor, Binding Post	7	19071B

The two cables (Items 1 and 2) are coaxial shielded leads useful for connections where low noise is essential. The 24" cable (Item 2) can be used to interconnect two instruments having UHF receptacles. The 30" cable (Item 1) can be used to connect to the circuit under test through the use of clip leads. A binding post adapter gives easy access to the electrometer "high" terminal. Two UHF female couplers (Item 3) permit cables to be connected together. The UHF "tee" connector simplifies galvanometric current measurements when using a current source and electrometer or picoammeter. Adapters (Items 4 and 5) are useful for conversion from UHF to BNC terminations.

Model 261 Picoampere Source

Description:

The Model 261 is an accurate picoampere current source with 3 digit resolution. The output ranges are 10^{-14} ampere to 1.1×10^{-4} ampere, positive or negative, in eight decade ranges. Accuracy is rated from $\pm$.25% to $\pm$1.6% exclusive of input drop considerations.

Application:

The Model 261 is a secondary standard for use in calibrating picoammeters and electrometers. It can also be used as an accurate current source for zero suppression and for galvanometric measurements.

Model 4003A Rack Mounting Kit

Description:

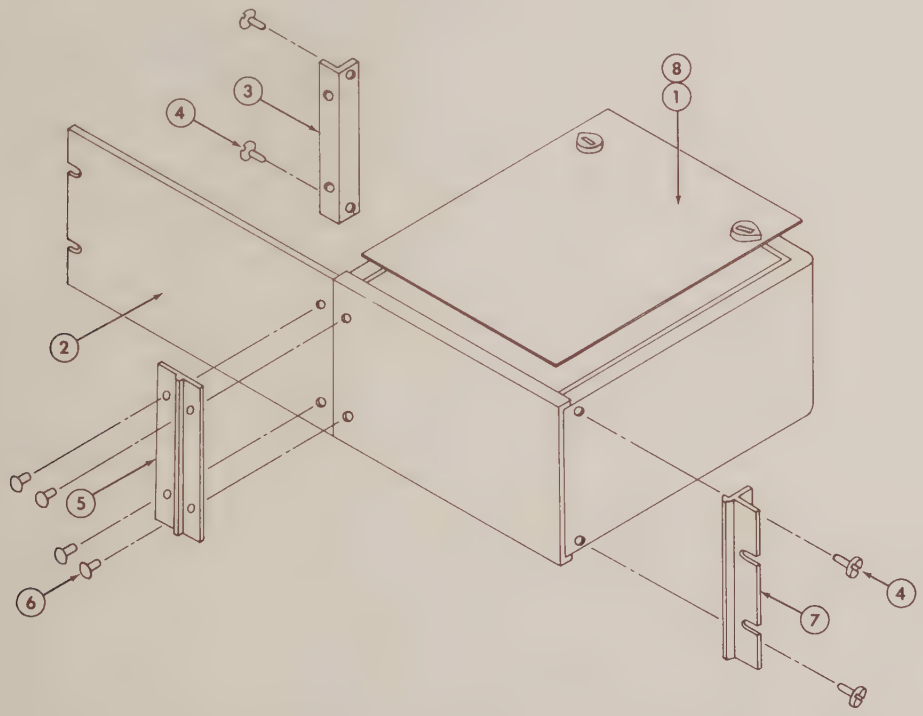
The Model 4003A is a rack mounting kit with overall dimensions, 5-1/4 inches high x 19 inches wide. Two top covers are provided for use with either 10 inch or 13 inch deep instruments.

Application:

The Model 4003A converts the instrument from bench mounting to rack mounting. It is suitable for mounting one instrument in one-half of a standard 19-inch rack.

Parts List:

Item No.	Description	Qty. Per Assembly	Keithley Part No.
1	Top Cover, 10"	1	18554B
2	Panel Adapter Plate	1	17452B
3	Angle Support	1	17476A
4	Screw,#10 x 3/8"	4	---
5	Connecting Plate	1	19126A
6	Screw, #10 x 1/2"	4	---
7	Angle	1	14624B
8	Top Cover, 13"	1	20015B



Model 4004A Dual Rack Mounting Kit

Description:

The Model 4004A is a rack mounting kit with overall dimensions, 5-1/4 inches high x 19 inches wide. Two top covers are provided for use with either 10 inch or 13 inch deep instruments.

Application:

The Model 4004A converts the instrument from bench mounting to rack mounting. It is suitable for mounting two instruments in a standard 19-inch rack.

Parts List:

Item No.	Description	Qty. Per Assembly	Keithley Part No.
1	Top Cover, 10"	2	18554B
4	Screw, #10 x 1/2	8	---
5	Connecting Plate	1	19126A
6	Screw, #10 x 1/2	4	---
7	Angle	2	14624B
8	Top Cover, 13"	2	20015B
9	Zee Bracket	1	19144A
10	Plate (not shown)	1	17454A

Models 240A, 244, 245, 246 Voltage Supplies

Description:

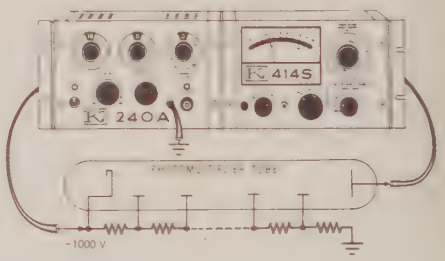
Keithley voltage supplies are highly-stable, low-noise power supplies for voltages up to ±3100 volts dc.

Application:

Keithley voltage supplies are commonly used with picoammeters in the measurement of resistance, light levels (photomultipliers), and radiation intensity (ion chambers). These high voltage supplies have been designed to operate with the Keithley line of electrometers, picoammeters and resistivity accessories. A typical application is shown using the Model 414S (or 414A) and the Model 240A in a photomultiplier experiment.

Output Ranges:

Model No.	Voltage
240A	0 to ±1200V
244	-200 to -2200V
245	0 to ±2100V
246	0 to ±3100V



Model 4104 Electronic Trip

The Model 4104 is an electronic trip installed in the picoammeter to provide automatic current control. Combinations of high, low, ± polarity, and latching is available.

Model 4109 Polarizing Supply

The Model 4109 provides +300 volts at 1 mA for applications requiring a stable voltage source. The Model 4109 can be ordered installed in the picoammeter if desired.

SECTION 7. REPLACEABLE PARTS

7-1. REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Model 414S. The List gives the circuit designation, the part description, a suggested manufacturer, the manufacturer's part number and the Keithley Part Number. The last column indicates the figure picturing the part. The name and address of the manufacturers listed in the "Mfg. Code" column are in Table 14.

7-2. HOW TO ORDER PARTS.

a. For parts orders, include the instrument's model and serial number, the Keithley Part Number, the circuit designation and a description of the part. All structural parts and those parts coded for Keithley manufacture (80164) must be ordered through Keithley Instruments, Inc., or its representatives. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

b. Order parts through your nearest Keithley representative or the Sales Service Department, Keithley Instruments, Inc.

TABLE 12. Abbreviations and Symbols.

A	Ampere	Fig.	Figure	Ω	ohm
CbVar	Carbon Variable	GCb	Glass Enclosed carbon	p	pico (10^{-12})
CerD	Ceramic, disc			Poly	Polystyrene
Comp	Composition	k	kilo (10^{3})		
				Ref.	Reference
DCb	Deposited Carbon	μ	micro (10^{-6})		
		M	Mega (10^{6})	V	Volt
EAl	Electrolytic, Aluminum	Mfr.	Manufacturer		
		Mtf	Metal Film	W	Watt
F	Farad	My	Mylar	WWVar	Wirewound Variable

MODEL 414S REPLACEABLE PARTS LIST
(Refer to Schematic Diagram 22394E for circuit designations.)

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
C101	.25 μF	400 V	My	13050	SM1A	C73-.25M	6
C102	.1 μF	400 V	My	13050	SM1A	C73-.1M	6
C103	.02 μF	1000 V	CerD	56289	10SS-S20	C22-.02M	6
C104	.02 μF	1000 V	CerD	56289	10SS-S20	C22-.02M	6
C105	.0047 μF	1000 V	CerD	56289	10SS-D47	C22-.0047M	6
C106	.0022 μF	1000 V	CerD	72982	811000X5F0222K	C22-.0022M	6
C107	680 pF	1000 V	CerD	71590	DD-681	C22-680P	6
C108	.01 μF	1000 V	CerD	56289	10SS-S10	C22-.01M	6
C109	.0033 μF	1000 V	CerD	56289	10SS-D33	V33-.0033M	6
C110	.0022 μF	1000 V	CerD	72982	811000X5F0222K	C22-.0022M	6
C111	680 pF	1000 V	CerD	71590	DD-681	C22-680P	6
C112	220 pF	500 V	Poly	71590	CPR-220J	C138-220P	6
C113	47 pF	500 V	Poly	71590	CPR-47J	C138-47P	6
C114	22 pF	500 V	Poly	71590	CPR-22J	C138-22P	6
C115	.0068 μF*	500 V	CerD	72982	851-Z5U0-682M	C22-.0068M	6

*Nominal value.

CAPACITORS (cont'd)

Circuit Desig.	Value	Rating	Type	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
C201	100 µF	40 V	EA1	73445	C437AR/G100	C150-100M	7
C202	.02 µF	1000 V	CerD	56289	10SS-S20	C22-.02M	7
C203	.02 µF	1000 V	CerD	56289	10SS-S20	C22-.02M	7
C204	100 µF	40 V	EA1	73445	C437AR/G100	C150-100M	7
C205	100 µF	40 V	EA1	73445	C437AR/G100	C150-100M	7
C206	.01 µF	1000 V	CerD	56289	10SS-S20	C22-.01M	7
C207	100 µF	40 V	EA1	73445	C437AR/G100	C150-100M	7

DIODES

Circuit Desig.	Type	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
D101	Silicon	01295	1N645	RF-14	7
D102	Silicon	02735	1N3255	RF-17	7
D103	Silicon	02735	1N3255	RF-17	7
D104	Zener	84970	VR47	DZ-30	7
D105	Silicon	02735	1N3255	RF-17	7
D106	Silicon	01295	1N645	RF-14	7
D107	Silicon	01295	1N645	RF-14	7
D201	Silicon	01295	1N645	RF-14	7
D202	Silicon	01295	1N645	RF-14	7
D203	Silicon	01295	1N645	RF-14	7
D204	Silicon	01295	1N645	RF-14	7
D205	Zener	12954	1N706	DZ-1	7
D206	Zener	12954	1N706	DZ-1	7
D207	Silicon	01295	1N645	RF-14	7
D208	Zener	04713	1N936	DZ-5	7

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
21850B	MOS FET Input Plug-in Card	80164		23734A	6
DS201	Pilot Light, Neon	91802	2190	PL-28	2
F201 (117V)	Fuse, Slow blow, 1/8 A	71400	MDL	FU-20	3
F201 (234V)	Fuse, Slow blow, 1/16 A	71400	MDL	FU-21	
J101	Printed Circuit Contacts	91662	02-005-113-6-200	CS-199	
P101	Printed Circuit Contacts, mate of J101	91662	02-005-111-5-200	CS-200	
J102	Receptacle, UHF, INPUT	91737	6804	CS-64	3
---	Plug, UHF, mate of J102	02660	83-822	CS-49	
---	Cap	91737	7901	CAP-4	
J103	Receptacle, Microphone, OUTPUT	02660	80-PC2F	CS-32	3
---	Plug, Microphone, mate of J103	02660	80-MC2M	CS-33	
M101	Meter	80164		ME-78	6
P201	AC Power Cable, 6 feet	93656	4638-13	CO-5	

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
S101	Rotary Switch, METER	80164		SW-244	2
---	Knob Assembly, Meter Switch	80164		21660A	
S102	Rotary Switch less components, SUPPRESSION	80164		SW-262	2
---	Rotary Switch with components, Suppression	80164		22135B	
---	Knob Assembly, Suppression Switch	80164		21660A	
S103	Rotary Switch less components, RANGE	80164		SW-243	2
---	Rotary Switch with components, Range	80164		21848B	
---	Knob Assembly, Range Switch	80164		21651A	
S104	Rotary Switch, Suppression Polarity	80164		SW-261	2
---	Rotary Switch with components, Polarity	80164		22136B	
---	Knob Assembly, Polarity Switch	80164		20382A	
S105	Slide Switch, 1 MA - 1 V	79727	G326	SW-45	3
S201	Slide Switch, 117 V - 234 V	80164		SW-151	3
---	Knob Assembly, 1 MA CAL Control	80164		16373A	
---	Knob Assembly, Suppression FINE Control	80164		16995A	
T201	Transformer	80164		TR-112	7

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
R101	10^{10} Ω	3%	GCb	63060	RX-1	R20-10^{10}	-
R102	10^{9} Ω	3%	GCb	63060	RX-1	R20-10^{9}	-
R103	10^{8} Ω	1%, 2 W	DCb	91637	DC-2	R14-100M	-
R104	10^{7} Ω	1%, 1/2 W	DCb	07716	DCC	R12-10M	-
R105	10^{6} Ω	1%, 1/2 W	DCb	91637	DCF-1/2	R12-1M	-
R106	10^{5} Ω	1%, 1/2 W	DCb	07716	DCC	R12-100K	-
R107	10^{4} Ω	1%, 1/2 W	DCb	07716	DCC	R12-10K	-
R108	10 kΩ	5%, 2 W	WWVar	12697	62JA	RP42-10K	-
R109	300 Ω	1%, 1/2 W	DCb	91637	DCF-1/2	R12-300	6
R110	1 kΩ	1%, 1/2 W	DCb	91637	DCF-1/2	R12-1K	6
R111	3 kΩ	1%, 1/2 W	DCb	07716	DCC	R12-3K	6
R112	10 kΩ	1%, 1/2 W	DCb	07716	DCC	R12-10K	6
R113	30 kΩ	1%, 1/2 W	DCb	91637	DCF-1/2	R12-30K	6
R114	100 kΩ	1%, 1 W	Epoxy	91637	MMF-1	R150-100K	6
R115	300 kΩ	1%, 1/2 W	DCb	07716	DCC	R12-300K	6
R116	1 MΩ	1%, 1/2 W	DCb	91637	DCF-1/2	R12-1M	6
R117	3 MΩ	1%, 1/2 W	DCb	91637	DCF-1/2	R12-3M	6
R118	10 MΩ	1%, 1/2 W	DCb	07716	DCC	R12-10M	6
R119	30 MΩ	1%, 1 W	DCb	91637	DC-1	R13-30M	6
R120	100 MΩ	1%, 2 W	DCb	91637	DC-2	R14-100M	6
R121	10^{9} Ω	3%	GCb	63060	RX-1	R20-10^{9}	6
R122	10^{10} Ω	3%	GCb	63060	RX-1	R20-10^{10}	6
R123	2 kΩ	1%, 1/2 W	MtF	07716	CEC	R61-2K	6
R124	1 kΩ	1/2%, 1/2W	MtF	07716	CEC	R61-1K	6
R125	1 MΩ	1%, 1/2 W	DCb	91637	DCF-1/2	R12-1M	7

RESISTORS (cont'd)

Circuit Desig.	Value	Rating	Type	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
R126**	100 kΩ	10%, 1/4 W	Comp	01121	CB	R76-100K	6
R127	5 kΩ	20%, 2 W	WWVar	71450	1NS-115	RP50-5K	7
R128	1 kΩ	10%, 5 W	WWVar	71450	AW	RP34-1K	7
R129	13 kΩ	1%, 1/2 W	DCb	91637	DCF-1/2	R12-13K	7
R130	18 kΩ	1%, 1/2 W	DCb	07716	DCC	R12-18K	7
R131	2 kΩ	20%, 0.2 W	CompV	71450		RP31-2K	2
R132	18 kΩ	1%, 1/2 W	DCb	07716	DCC	R12-18K	7
R133	15 kΩ	10%. 1/2 W	Comp	01121	EB	R1-15K	7
R134	2.2 kΩ	10%, 1/2 W	Comp	01121	EB	R1-2.2K	7
R135	680 Ω	10%, 1/2 W	Comp	01121	EB	R1-680	7
R136	4.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-4.7K	7
R137	1.2 kΩ	10%, 2 W	Comp	01121	HB	R3-1.2K	7
R138	2 kΩ	1%, 1/2 W	DCb	07716	DCC	R12-2K	7
R139	2 kΩ	20%, 2 W	WWVar	71450	1NS-115	RP50-2K	7
R140	1 kΩ	1/2%, 1/2 W	MtF	07716	CEC	R61-1K	7
R141	1 kΩ	10%, 5 W	WWVar	71450	AW	RP34-1K	3
R142	1 kΩ	1/2%, 1/2 W	MtF	07716	CEC	R61-1K	6
R143	1 kΩ	1/2%, 1/2 W	MtF	07716	CEC	R61-1K	6
R201	27 kΩ	10%, 1/2 W	Comp	01121	EB	R1-27K	7
R202	2.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-2.7K	7
R203	47 kΩ	10%, 1/2 W	Comp	01121	EB	R1-47K	7
R204	4.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-4.7K	7
R205	47 kΩ	10%, 1/2 W	Comp	01121	EB	R1-47K	7
R206	47 Ω	10%, 1/2 W	Comp	01121	EB	R1-47	7
R207	4.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-4.7K	7
R208	4.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-4.7K	7
R209	100 kΩ	10%, 1/2 W	Comp	01121	EB	R1-100K	7
R210	82 kΩ	10%, 1/2 W	Comp	01121	EB	R1-82K	7
R211	4.7 kΩ	1/2%, 1/2 W	MtF	07716	CEC	R61-4.7K	7
R212	4.7 kΩ	1/2%, 1/2 W	MtF	07716	CEC	R61-4.7K	7
R213	2.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-2.7K	7
R214	47 kΩ	10%, 1/2 W	Comp	01121	EB	R1-47K	7
R215	47 Ω	10%, 1/2 W	Comp	01121	EB	R1-47	7
R216	4.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-4.7K	7
R217	47 kΩ	10%, 1/2 W	Comp	01121	EB	R1-47K	7
R218	2.7 kΩ	10%, 1/2 W	Comp	01121	EB	R1-2.7K	7
R219	100 kΩ	10%, 1/2 W	Comp	01121	EB	R1-100K	7
R220	47 kΩ	10%, 1/2 W	Comp	01121	EB	R1-47K	7
R221	22 kΩ	1/2%, 1/2 W	MtF	07716	CEC	R61-22K	7
R222	10 kΩ	20%, 2 W	WWVar	71450	1NS-115	RP50-10K	7
R223	91 kΩ	1/2%, 1/2 W	MtF	07716	CEC	R61-91K	7
R224	27 kΩ	10%, 1/2 W	Comp	01121	EB	R1-27K	7

TRANSISTORS

Circuit Desig.	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
Q101**	80164		20933A	6
Q102**	80164		20933A	6
Q103	80164		21675A	7
Q104	80164		21675A	7
Q105	04713	2N3904	TG-47	7

** Replace R126, Q101 or Q102 by ordering Plug-in Board 23734A.

TRANSISTORS (cont'd)

Circuit Desig.	Mfr. Code	Mfr. Desig.	Keithley Part No.	Fig. Ref.
Q106	71279	ES-5321	TG-54	7
Q201	02734	40317	TG-43	7
Q202	07263	2N3565	TG-39	7
Q203	07263	2N3565	TG-39	7
Q204	07263	2N3565	TG-39	7
Q205	07263	2N3565	TG-39	7
Q206	07263	2N3565	TG-39	7
Q207	07263	2N3565	TG-39	7
Q208	02734	40319	TG-50	7
Q209	07263	S17638	TG-33	7
Q210	07263	S17638	TG-33	7
Q211	07263	S17638	TG-33	7
Q212	07263	S17638	TG-33	7
Q213	07263	S17638	TG-33	7

TABLE 13.
Mechanical Parts List

Description	Quantity Per Assembly	Keithley Part No.	Fig. Ref.
1) Chassis	1	24021B	8
11) Front Panel	1	21658C	
Top Cover Assembly	---	18553B	8
12) Cover, Sheet Metal	1	17131D	
13) Screws	4	---	
Handle Assembly	---	---	
14) Handle	1	HH-18	
15) Screws #6-32 x 3/8" R.H. Slotted	2	---	
Bottom Cover Assembly	---	19298C	9
2) Cover	1	19340B	
3) Fastener	2	FA-54	
Feet Assembly	---	---	
4) Feet	4	FE-5	
5) Ball	4	FE-6	
6) Screws #8-32 x 3/8" Phillips, Pan Head	4	---	
Tilt Bail Assembly	---	---	
7) Bail	1	17147B	
8) Right Assembly	1	19206B	
9) Left Assembly	1	19205B	
10) Screws #6-32 x 1/4" Phillips, Pan Head	2	---	

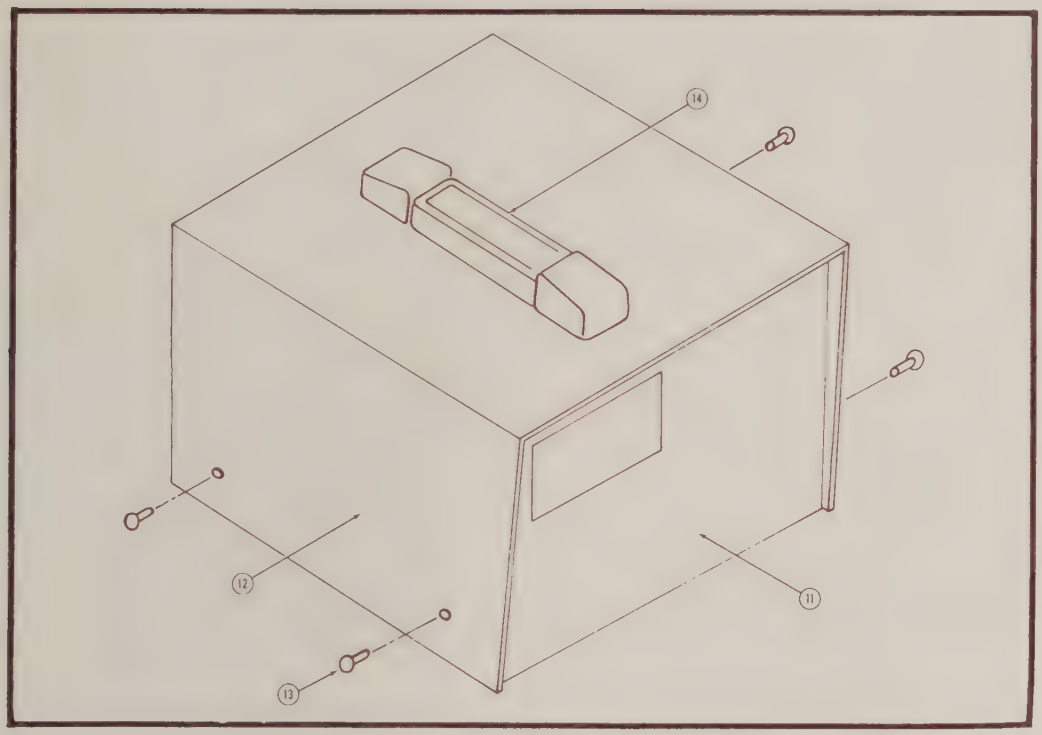


FIGURE 8. Top Cover Assembly.

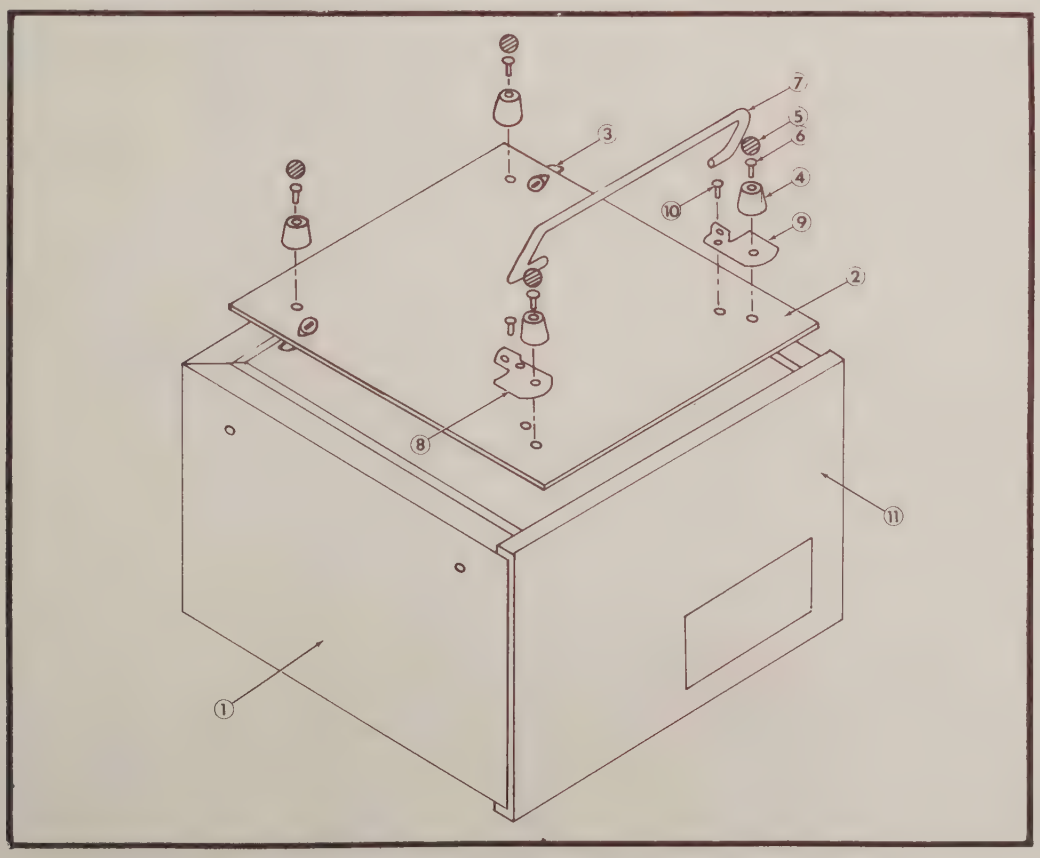
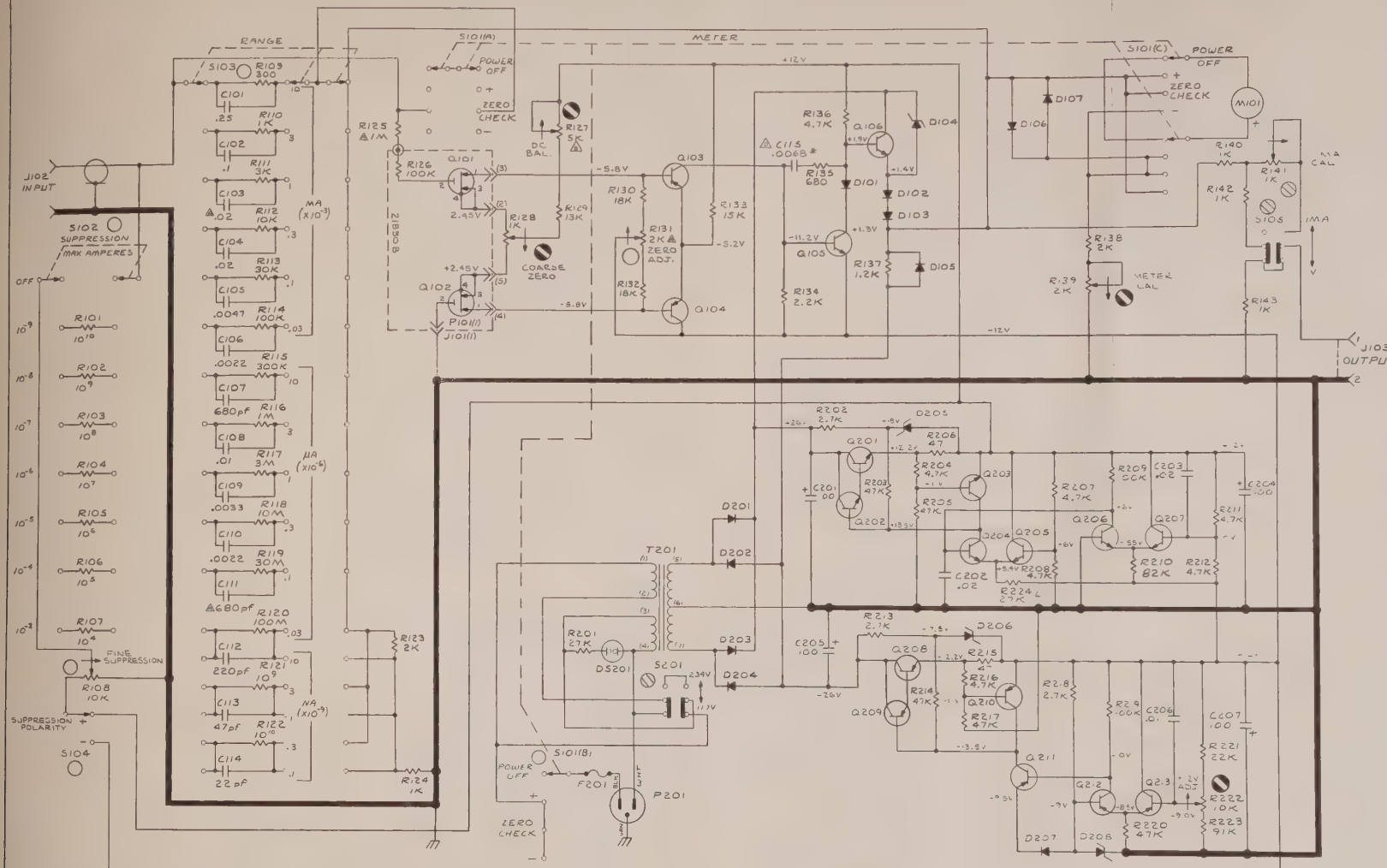


FIGURE 9. Bottom Cover Assembly.

TABLE 14.
Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1).

01121	Allen-Bradley Corp. 1201 South 2nd Street Milwaukee, Wis. 53204
01295	Texas Instruments, Inc. Semiconductor-Components Division 13500 North Central Expressway Dallas, Texas 75231
02660	Amphenol Corp. 2801 South 25th Avenue Broadview, Chicago, Illinois 60153
02735	Radio Corporation of America Commercial Receiving Tube and Semiconductor Division Somerville, N.J.
04713	Motorola, Inc. Semiconductor Products Division 5005 East McDowell Road Phoenix, Arizona 85008
07716	International Resistance Co. 2850 Mt. Pleasant Burlington, Iowa 52601
12954	Dickson Electronics Corp. 302 S. Wells Fargo Avenue Scottsdale, Ariz.
13050	Potter Co. Highway 51 N. Wesson, Miss. 39191
63060	Victoreen Instrument Co. 5806 Hough Avenue Cleveland, Ohio 44103
71279	Cambridge Thermionic Corp. 430 Concord Avenue Cambridge, Mass.
71400	Bussmann Mfg. Div. of McGraw-Edison Co. 2538 W. University St. St. Louis, Mo.
71450	CTS Corp. 1142 W. Beardsley Ave. Elkhart, Ind.
71590	Centralab Division of Globe-Union, Inc. 932 E. Keefe Ave. Milwaukee, Wis. 53212
72982	Erie Technological Products, Inc. 644 W. 12th Street Erie, Pa. 16512
73445	Amperex Electronic Co. Division of North American Phillips Co., Inc. Hicksville, N.Y.
79727	Continental-Wirt Electronics Corp. Philadelphia, Pa.
80164	Keithley Instruments, Inc. 28775 Aurora Road Cleveland, Ohio 44139
84970	Sarkes Tarzian, Inc. E. Hillside Drive Bloomington, Ind.
91637	Dale Electronics, Inc. P.O. Box 609 Columbus, Nebr. 68601
91662	Elco Corp. Willow Grove, Pa.
91737	Gremar Mfg. Co., Inc. 7 North Avenue Wakefield, Mass.
91802	Industrial Devices, Inc. 982 River Road Edgewater, N.J. 07020
93656	Electric Cord. Co. 1275 Bloomfield Avenue Caldwell, N.J.



NOTES:
1. ALL RESISTANCE & CAPACITANCE SHALL BE DESIGNATED IN OHMS & MICROFARADS UNLESS OTHERWISE NOTED
2. ◯ - FRONT PANEL CONTROL.
3. ◑ INTERNAL SCREWDRIVER ADJ.
4. ◑ REAR PANEL CONTROL.
5. M - MEGOHM.
6. K - 1000 OHM.
7. pf - PICOFARAD.
8. ↕ - CLOCKWISE ROTATION.
9. * - INDICATES NOMINAL VALUE

HIGHEST REFERENCE DESIGNATION

R143	C115	D107	Q106
S105	J 03	M101	R224
C207	D208	Q213	S201
T201	DS201	F201	P201

REFERENCE DESIGNATION NOT USED

REVISIONS

LTR	ECO NO.	APPD	DATE
A	3500	WP	4-24-68
B	3510	WJ	5-3-68
	3541	CMV	7-[illegible]

DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED: FRAC ± 1/64, DEC ± .009, ANG ± 1°
DO NOT SCALE

DRN	WP	DATE 3-7-68
CKD	[illegible]	DATE 3-7-68
ENG APPR	[illegible]	DATE 3-28-68
PROJ RELEASE		DATE
PROD RELEASE		DATE

KEITHLEY INSTRUMENTS CLEVELAND OHIO

MATERIAL
FINISH
NEXT ASSEMBLY
USED ON

TITLE SCHEMATIC PICOAMMETER

PART NUMBER 22394E

KEITHLEY INSTRUMENTS, INC.
28775 AURORA ROAD
CLEVELAND, OHIO 44139

SERVICE FORM

MODEL NO._____ SERIAL NO._____ P.O. NO._____ DATE_____ R-

NAME _____ PHONE _____

COMPANY _____

ADDRESS _____ CITY _____ STATE _____ ZIP_____

1. Describe problem and symptoms using quantitative data whenever possible (enclose readings, chart recordings, etc.) _____

_____

_____ (Attach additional sheets as necessary).

2. Show a block diagram of your measurement system including all instruments connected (whether power is turned on or not). Also describe signal source.

3. List the positions of all controls and switches on both front and rear panels of the instrument. _____

_____

4. Describe input signal source levels, frequencies, etc. _____

_____

_____

5. List and describe all cables used in the experiment (length, shielding, etc.).

_____

_____

6. List and describe all other equipment used in the experiment. Give control settings for each. _____

_____

_____

7. Environment:
   Where is the measurement being performed? (Factory, controlled laboratory, out-of-doors, etc.) _____
   What power line voltage is used? _____ Variation? _____ Frequency? _____
   Ambient temperature? _____°F. Variation? _____°F. Rel. Humidity? _____
   Other _____

8. Additional Information. (If special modifications have been made by the user, please describe below.) _____

_____

KEITHLEY

Keithley Instruments, Inc./28775 Aurora Road/Cleveland, Ohio 44139/U.S.A./(216) 248-0400/Telex: 98-5469
Keithley Instruments GmbH/Heiglhofstrasse 5/D-8000 München 70/WEST GERMANY/(089) 714-40-65/Telex: 521 21 60
Keithley Instruments, Ltd./1, Boulton Road/GB-Reading, Berkshire RG2 ONL/GREAT BRITAIN/(0734) 86 12 87/Telex: 847047
Keithley Instruments SARL/2 Bis, Rue Léon Blum/B.P. 60/91121 Palaiseau Cedex/FRANCE/(6) 011.51.55/Telex: 600933F
Keithley Instruments B.V./Leidsestraatweg 149/Postbus 1190 /NL-Woerden/NETHERLANDS/(03480) 13 643/Telex: 40 311
Keithley Instruments SA/Filiale Dübendorf/Kriesbachstr. 4/CH-8600 Dübendorf/SWITZERLAND/01 821 94 44/Telex: 57 536
Keithley Instruments Handels-Gesellschaft m.b.H./Döblinger Hauptstr. 32/A-1190 Wien /AUSTRIA/0222 314 289/Telex: 13 45 00